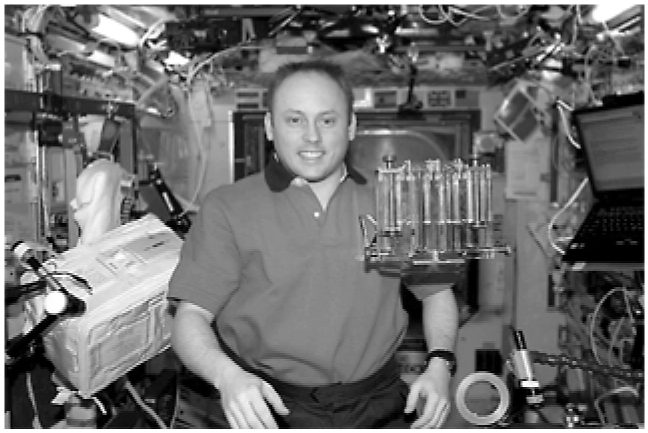
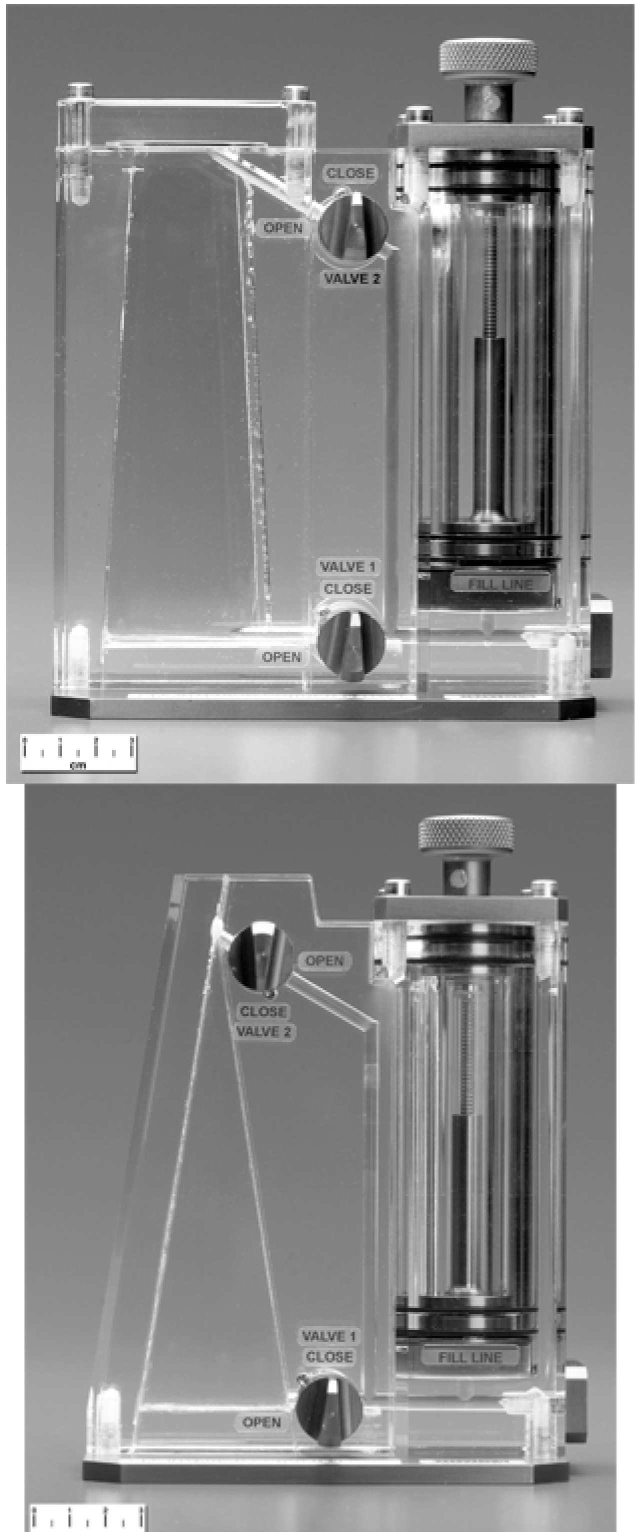
Capillary Flow Experiments Began on the International Space Station



Science Officer Mike Fincke performs the CFE on orbit on Expedition 9 as a part of Saturday Science.

The Capillary Flow Experiments (CFEs) are a suite of fluid physics flight experiments designed to investigate capillary flows and phenomena in low gravity. Data obtained from the CFEs will be crucial to NASA's Space Exploration Initiative, particularly pertaining to fluids management systems such as fuels and cryogen storage systems, thermal control systems (e.g., water recycling), and materials processing in the liquid state. NASA's current plans for exploration missions assume the use of larger liquid propellant masses than have ever flown on interplanetary missions. Under low-gravity conditions, capillary forces can be exploited to control fluid orientation so that such large mission-critical systems perform predictably. The first of the CFE experiments has been conducted on the International Space Station, and the data are being analyzed. The experiment suite is described briefly.

CFE is a simple fundamental scientific study that can yield quantitative results from safe, low-cost, short time-to-flight, hand-held fluids experiments. The experiments aim to provide results of critical interest to the capillary flow community that cannot be achieved in ground-based tests: for example, dynamic effects associated with a moving-contact boundary condition, capillary-driven flow in interior corner networks, and critical wetting phenomena in complex geometries. Specific applications of the results center on particular fluids challenges concerning propellant tanks. The knowledge gained will help spacecraft fluid systems designers increase system reliability, decrease system mass, and reduce overall system complexity.



Interior Corner Flow units. Left: ICF-1 has a triangular cross section in the horizontal plane of the test section. Right: ICF-2 is a tapered triangle from the base to the top and has a rectangular cross section in the horizontal plane of the test section.

CFE is a NASA Glenn Research Center experiment developed under contract by ZIN Technologies, Inc. Three experiments constitute CFE--the Interior Corner Flow (ICF), the Vane Gap (VG), and the Contact Line (CL) experiments; and each experiment has two unique experimental units. All units use similar fluid-injection hardware, have simple and similarly sized test chambers, and rely solely on video for highly quantitative data. Silicone oil is the fluid used for all the tests, with different viscosities depending on the unit. Differences between units are primarily fluid properties, wetting conditions, and test cell cross section. The experiment procedures are simple and intuitive.

Vane Gap unit 1. VG-1 and VG-2 are nearly identical, but VG-2 has a coating along the interior surfaces that changes the wetting characteristics of the fluid. VG-2 also has a slightly thicker vane than VG-1. This changes the interaction of the fluid with the vane and the side wall.

ICF is designed to understand propellant management and passive capillary flow in tapered geometries for which boundary conditions are not well understood or modeled. VG is designed to investigate the critical wetting condition that arises between interior corners that do not actually make contact, in particular, the corner and gap formed by an interior vane and the interior wall of a propellant tank, or between the intersection of vanes in a complex vane network.

The CL experiment is designed to study a fundamental and practical concern for low-gravity fluid phenomena: the impact of the dynamic contact line. The contact line controls the interface shape, stability, and dynamics of capillary systems in low gravity. The CFE-CL experiments will provide a direct measure of the extremes inbehavior expected from either a free or pinned contact-line condition. There are two CL units, identical except for their respective wetting characteristics. One of the two CL units is shown in the bottom right photograph on the preceding page.

Contact Line unit 2. CL–2 flight unit showing pinning edge in right-center fluid chamber.
Long description of figure. The unit is made of a single block of Plexiglas (polymethylmethacrylate, or PMMA). Within the unit are two reservoirs that each feed the two fluid test cylinders by a turning knob-driven piston. The test cylinders are geometrically identical with the important exception that the left cylinder is completely smooth whereas the right cylinder has a pinning edge, approximately one-third of the distance above the base. In addition, above the contact line in the right fluid cylinder, a nonwetting film is deposited on the inner surface to allow the fluid to return to the pinned condition between experimental runs.

Contact Line unit 1 (CL-1), the ICF units, and VG units are complete and awaiting launch. Contact Line unit 2 (CL-2) was launched to the space station on Progress 13 in January 2004. International Space Station Science Officer Michael Fincke operated CL-2 on August 28 and again on September 18, 2004. He induced a variety of fluid disturbances, including taps, slides, and multiple lateral and axial perturbations. Video data were taken and are being analyzed by Principal Investigator Mark Weislogel at Portland State University under a grant from Glenn.

The following observations have been made. The correct contact-line boundary condition is pivotal to accurate modeling of large-length-scale capillary surface dynamics. Large-amplitude lateral oscillations created an hourglass configuration in the smooth cylinder, but the pinned interface did not de-pin. Under certain conditions, the pinned interface natural frequency was twice that of the smooth cylinder, and flows predominantly parallel to the contact line did not change the frequency or settling times.

Find out more about this research:
Mark Weislogel's Web site at http://www.me.pdx.edu/~mmw/
AIAA paper describing CFE at http://www.me.pdx.edu/~mmw/AIAACFE.pdf

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